OVERLOADING AND SPURIOUS RESPONSES IN TRANSISTOR FM TUNERS

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SUMMARY

A transistor, when used as a mixer in an FM tuner, will produce spurious responses that cause interference from other FM stations.

The use of two mixer diodes in a balanced circuit to minimize this type of response is shown. Also described is a double-tuned circuit ahead of the r-f stage which will improve the spurious response ratio along with a decreased possibility of overloading the r-f amplifier.

I. INTRODUCTION

This paper is concerned with the problem of spurious responses caused by the generation of subharmonics of the i-f frequency. The local oscillator beats with all signals present at the mixer input; some of the resulting frequencies are subharmonics of the i-f (10.7 mc) which, in turn, produce harmonics within the i-f passband. These spurious responses are only noticeable on extremely strong signals such as encountered in high FM density metropolitan areas, but they can be troublesome. And, in addition to the usual image and intermediate frequency response, they limit the overall spurious response ratio.

A possible solution to the problem is to use a double-tuned preselector and a balanced diode mixer. Experimental results show that an improvement in the overall spurious response ratio of 15 db or more can be obtained.

Under the usual conditions, a transistor mixer is biased so that its base-emitter diode is always forward biased and quadratic mixing takes place. If the curve of base current vs. base voltage is truly square-law, its power series representation about the operating point will contain only three terms, a d-c term, a linear term, and a quadratic term, as follows:

$$i = a_0 + a_1 e + a_2 e^2 \qquad (1)$$

Under these conditions when two sine waves are mixed, the output will contain the difference frequency component free of harmonics. In the practical case, more terms must be added to the power series to get a more complete picture.

Of these, each of the higher even order terms such as the 4th, 6th, etc., will cause harmonics of the difference frequency to appear. As some of the difference frequencies between the undesired signal and the local oscillator frequency equal subharmonics of the i-f frequency, they show up as spurious responses, and a very strong station may be heard at several points on the dial. This type of interference will be called the subharmonic mixer response (SMR).

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II. SPURIOUS RESPONSES

Of the six common spurious responses of an FM tuner, only the subharmonic mixer response can fall within the FM band (Fig. 1). The r-f preselector will normally eliminate the common spurious responses that are outside of the band. The main SMR lies at 5.35 mc away from the desired signal where the preselector provides only limited rejection (Fig. 2).

As can be seen from the oscillogram of the output of an FM tuner (Fig. 3) there are other responses that occur within the FM band, but the important ones are due to SMR.

The frequency deviation for the 2nd SMR is doubled, and as we are looking at the tuner's overall response, the slope of the S curve is also doubled. This will double the sound output voltage, and at the higher levels of modulation, distortion will occur due to over-modulation. The listener may inadvertently tune in the 2nd SMR response, which may be louder but somewhat distorted.

As the level of input voltage is reduced from 1 volt to 10 mV, we find only the desired response remaining at the tuner's output.

Possible Solutions to SMR Spurious Responses

A number of partial solutions to the problem of SMR exist and are in use today in FM tuners:

1. A local-distance switch, which either applies a fixed attenuator ahead of the r-f stage or reduces the gain of the r-f stage.
2. A high Q single-tuned circuit ahead of the r-f stage. Both of these give reduction to SMR but also increase the noise figure of the tuner. A high Q single-tuned circuit could also be used in the collector of the r-f stage where its insertion loss would not add significantly to the tuner's overall noise figure.
3. A double-tuned circuit ahead of the r-f stage instead of a single-tuned circuit.

By keeping the insertion loss of both the single-tuned and the double-tuned circuits at 2 db, an SMR reduction of 10.2 db is gained by using the double-tuned circuit (Fig. 2). The insertion loss adds directly to the noise figure, which reduces the tuner's usuable sensitivity. A maximum of 2 db is about all the insertion loss that is permissible without degrading the tuner's performance.

For single-tuned and critically coupled double-tuned circuits, the insertion loss in db is given by line 4, Fig. 2. The 3-db bandwidth changes from 1.63 mc to 2.29 mc when replacing a single-tuned circuit with a double-tuned circuit. In both cases the bandwidth is more than adequate for FM reception.

III. DIODE MIXERS

In the majority of diode mixer circuits, the diode is reverse biased, so that it conducts on the peaks of the injection voltage. This type of operation is called piecewise-linear as compared to quadratic mixing when the diode is forward biased.

In piecewise-linear operation the r-f signal voltage is much smaller than the local-oscillator voltage. Under these conditions the conductance of the diode will vary as a function of the larger voltage only and SMR will be small. In order to keep the local oscillator voltage level less than 0.5 volt and still prevent SMR on large signals, quadratic mixing with its forward biasing can be used. In this case, if the diode's current-vs-voltage curve is entirely square-law, no SMR will occur regardless of the relative sizes of the two voltages.

In choosing a diode for a mixer application, an important consideration is the diode's recovery time because of its effect on conversion gain.

As seen from the photo in Fig. 4, the recovery time of the FD-7 is less than the FD-100. On the basis of recovery time, the FD-7 is the better choice for a mixer diode. It is a very small geometry silicon planar epitaxial device with storage characteristics similar to the widely used 1N82A diode.

Undesired Signal (f_x)	Name or Cause Spurious Response
f_s+2f_i	Image Response
f_i	Intermediate Frequency Responce
$2f_s+f_i$	2nd Order Image Response
f_{s_2}; f_{s_3}	Overloading of the RF Stage
$2(f_s+f_i)+f$	2nd Harmonic of Local Oscillator BeatsWith f_x
$f_s+f_i\left[\frac{n-1}{n}\right]$ $n+2,3,4,...$	Subharmonic Mixer Response

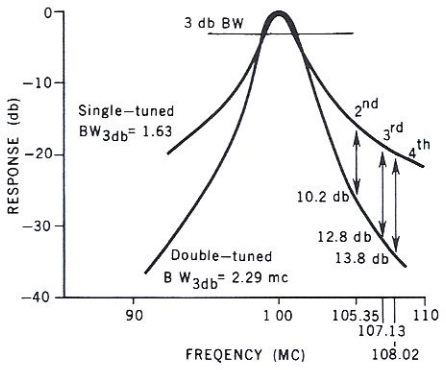
f_x = Undesired Signal

f_s = Dial Setting of FM Tuner

f_i = Intermediate Frequency (10.7mc)

(Local Oscillator Frequency 10.7mc higher than dial setting)

FIG. 1. Table of Common Spurious Responses of an FM Tuner.



1. Both circuits have the same insertion loss (I.L.) of 2 db each.
2. Unloaded Q (Q_u) of both circuits equals 300.
3. Loaded Q_L (Q_L) of both circuits equals 61.5.
4. $I L_{db}= 20 \log (1 - \frac{Q_L}{Q_u})$.
5. $kQ_L = 1$ for doubletuned circuit (critically coupled).

FIG. 2. Comparisons of Single and Double Tuned Preselectors for Reception of Subharmonic Mixer Responses.

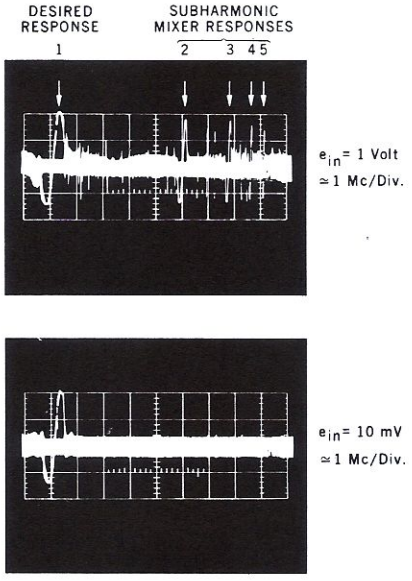


FIG. 3. Output of FM Tuner Showing Spurious Responses Near Desired Signal Response.

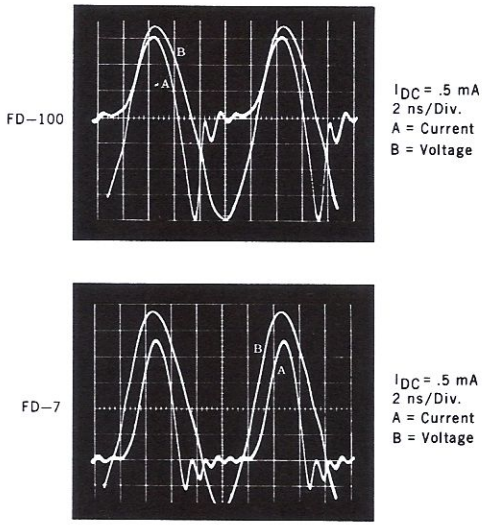
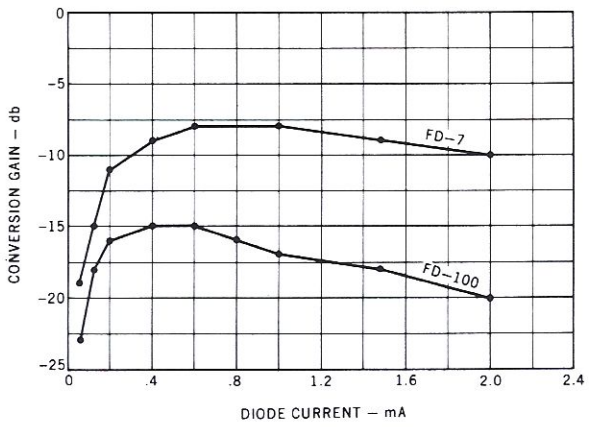


FIG. 4. Voltage and Current Waveforms Showing the Effect of Diode Recovery Time.

These photographs were taken at a frequency of 100 mc and at a forward diode current of 0.5 milliampere. The current waveform would appear as a half sine wave if the effect of storage was absent.

The choice of a diode on the basis of its shorter recovery time is shown to be correct in the conversion gain graph of Fig. 5. The FD-7 has 6 db more G_c than that of the FD-100.



The FD-7 with smaller recovery time has the higher conversion.
L.O. Injection = 200mV
$R_S = R_L = 220\,\Omega$

FIG. 5. Single Diode Conversion Gain vs. Diode Current.

Balanced Diode Mixers

The curve of diode current vs voltage can be expanded about the operating point by means of a power series, providing the diode's recovery time is short and the diode is always conducting. Figure 6 shows the general equations of difference terms with single and balanced diode mixers.

The value (e) is the instantaneous voltage across the diode, including the biasing voltage. By adding two voltage generators representing the local oscillator voltage (e_o) and the incoming signal voltage (e_s) in series with the diode so that $e = e_o + e_s$, the expression can be expanded. Note that only the even order terms contribute to the desired difference frequency and harmonics thereof.

Arranging two diodes in a balanced circuit and computing the total current flow, (i), note that the 2nd and 4th harmonics of the difference frequency are canceled out, leaving only the 3rd harmonic.

IV. EXPERIMENTAL RESULTS

To test the balanced diode mixer, the circuit of Fig. 7 was constructed. The local oscillator voltage was applied to the diodes in push-pull from a low impedance of 10 ohms.

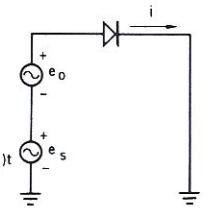
Diode Power Series Expansion

$$i = a_0 + a_1 e + a_2 e^2 + a_3 e^3 + \cdots$$

Single Diode Mixer

$$e_o = E_{DC} + E_o \cos w_o t$$
$$e_s = E_S \cos w_s t$$

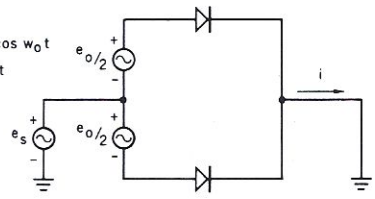
$$i = A_2\cos(w_o - w_s)t + A_4\cos(w_o - w_s)t + B_4\cos 2(w_o - w_s)t + A_6\cos(w_o - w_s)t + B_6\cos 2(w_o - w_s)t + C_6\cos 3(w_o - w_s)t + A_8\cos(w_o - w_s)t + B_8\cos 2(w_o - w_s)t + C_8\cos 3(w_o - w_s)t + D_8\cos 4(w_o - w_s)t + \cdots$$



Balanced Diode Mixer

$$e_o = E_{DC} + E_o \cos w_o t$$
$$e_s = E_S \cos w_s t$$

$$i = A_2\cos(w_o - w_s)t + A_4\cos(w_o - w_s)t + A_6\cos(w_o - w_s)t + B_6\cos 3(w_o - w_s)t + A_8\cos(w_o - w_s)t + B_8\cos 3(w_o - w_s)t$$



(Subscripts of coefficients indicate the order of the power series expansion from which the difference terms arise.)

FIG. 6. General Equations of Difference Terms with Single and Balanced Diode Mixers.

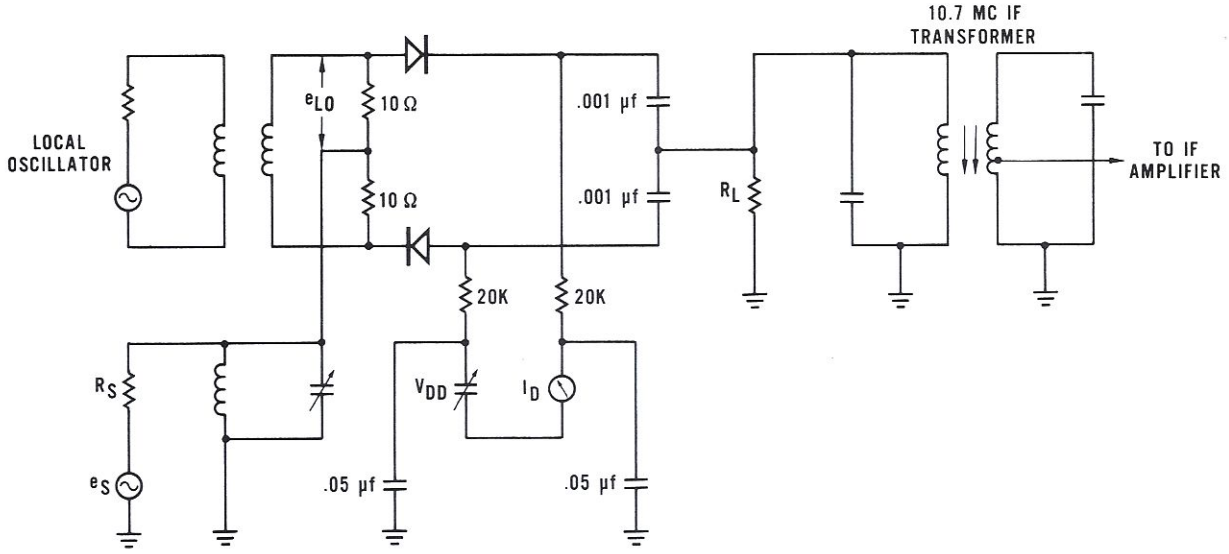


FIG. 7. Balance Diode Mixer — Test Circuit.

The signal voltage input was applied symmetrically to the diodes from R_S, a 220 ohm impedance. Forward bias to the diodes was supplied from a current source, maintaining the same current through both diodes.

In an FM tuner that has a usable sensitivity of 5 microvolts, and a gain of 20 db in the r-f stage, approximately 50 microvolts would be applied to the mixer; therefore, this value was used as a reference voltage for zero db.

In Fig. 8 the conversion gain is a function of the local oscillator voltage and reaches a maximum of -6 db at 200 millivolts in the balanced case. A comparison at 200 mV of the 2nd harmonic response in the single diode case to that of the balanced diode mixer shows a 17 db gain reduction. At the same 200 millivolt level, 3rd harmonic response does not change.

Setting the local oscillator injection voltage at 200 millivolts and varying the diode bias current, a maximum conversion gain of -6 db occurs at 0.6 mA for the balanced case as shown in Fig. 9. Here again, note that the 2nd harmonic is reduced 17 db in going from the single to the balanced diode mixer at 0.6 mA bias current. The 3rd harmonic remains substantially the same in both the balanced mixer and single diode mixer.

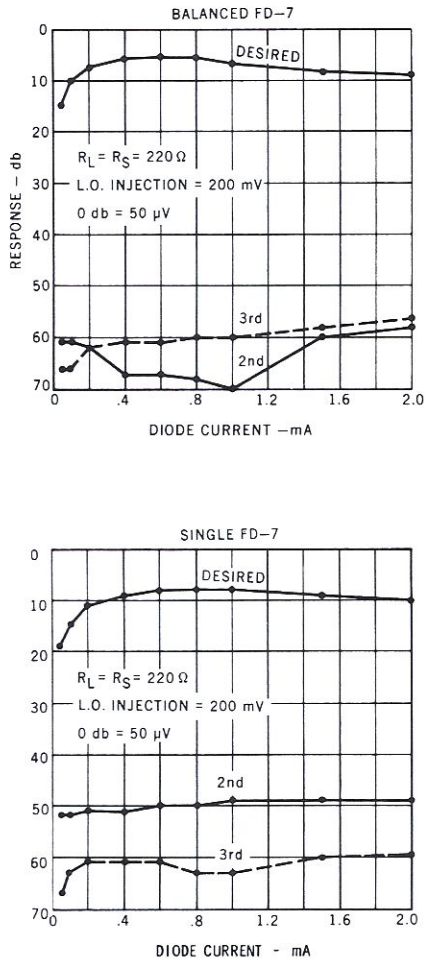


FIG. 8. Desired and 2nd and 3rd Subharmonic Mixer Responses vs. Local Oscillator Injection.

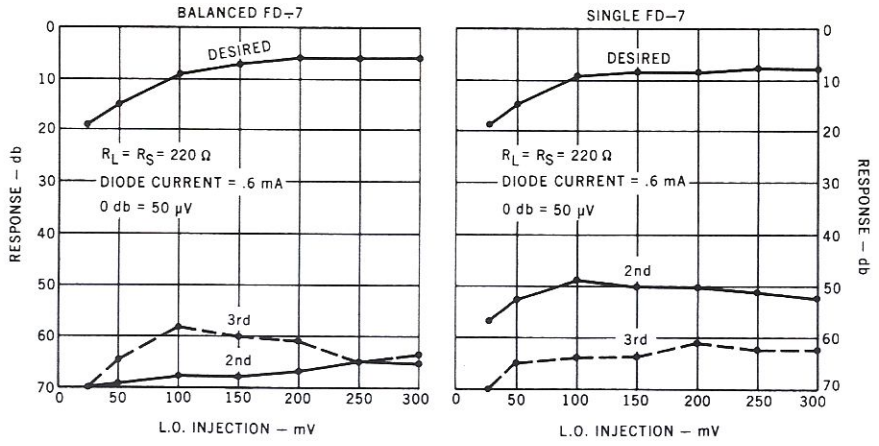


FIG. 9. Desired and 2nd and 3rd Subharmonic Mixer Responses vs. Diode Current.

A single-tuned preselector tuner with either a transistor mixer or a single diode mixer will have a spurious rejection ratio of the 2nd SMR of 75 db (Fig. 10).

By changing to a balanced diode mixer this ratio can be improved by 19 db. Again the 3rd SMR remained about the same and, in the balanced case, it is apppoximately equal to the 2nd SMR (94-93 db).

By using a double-tuned preselector about 17 db can be added to these figures.

V. CONCLUSION

The limitations of a transistor mixer in regard to subharmonic mixer responses can be improved upon by the use of a balanced diode mixer. By careful adjustment of the operating point and the amount of local oscillator voltage, good conversion gain can be had, along with a high order of rejection to SMR.

	Single Diode Mixer		Balanced Diode Mixer	
SMR	**2nd**	**3rd**	**2nd**	**3rd**
Single Tuned Preselector	75 db	91 db	94 db	93 db
Double Tuned Preselector	88 db	105 db	104 db	106 db

L.O. Injection = 200 mV
Diode Current = 0.6 mA
Diode Type FD 7

FIG. 10. FM Tuner Spurious Rejection Ratios of Subharmonic Mixer Responses.